

TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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DURALUMIN, ITS PROPERTIES AND USES.

By R. Beck.

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Historical Sketch.

It is worth while for us, as Germans, to establish the fact that duralumin is a German discovery and therefore a present of German scientific research to the metal industries of all civilized countries. The contrary opinion is occasionally met in the newspapers and periodicals of other countries. Such statements are not necessarily malicious, but should, nevertheless, not remain unchallenged. For example, the English periodical "The Engineer," of December 7, 1923, contained the following footnote to the translation of a German article on duralumin:

"Duralumin in the German original from which this article has been prepared, but, as this word represents a proprietary article in this country and as the German alloy corresponding to it is said to be definitely different from the British-made material, we prefer to use the expression aluminium alloy."

Thus it appears that the editor prefers to employ the term "duralumin" only for the alloy of English origin and to designate the German alloy as "aluminium alloy." I here wish to correct the error of the editor of "The Engineer" by stating that the word "duralumin"

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\* From "Zeitschrift fur Metallkunde," April, 1924, pp. 122-127.

is also of German origin. It was patented by the Düren Metal Works in the German Empire, under the patent number D.8130, Class 9a, on October 8, 1909, and consequently before the sale of the right of manufacture to any foreign country.

The claim that the English duralumin differs in its composition from the German duralumin, is inconclusive. The English manufacturers of duralumin still employ the formulas they obtained from the inventor, Alfred Wilm of Berlin, as I have proven by many analyses.

The process of manufacture has been patented in nearly all civilized countries. Vickers Sons and Maxim, Ltd., London, obtained the patent rights for England from the inventor in 1910, and began to manufacture duralumin in Birmingham in 1911. This firm ceded the French rights to the "Société du Duralumin" (Duralumin Company) in Dives. The American patent was confiscated during the World War and the rights of manufacture were given to the Aluminum Company of America, The International Aluminum Company in Detroit and the Baush Machine and Tool Company in Springfield, Massachusetts.

Patents were taken out in Denmark, Sweden, Norway, Switzerland, Holland, Belgium and Austria-Hungary. The war prevented the taking out of patents in Russia and Japan. Japan is said to have been making duralumin for some time in Osaka; and Russia in Moscow. Foreign manufacturers, without exception, call their products "duralumin." There is already a considerable literature on duralumin, both in Germany and in other countries.

The process of manufacture was no chance discovery, but the result of many years of research in a well-equipped laboratory

(Zentralstelle für wissenschaftlich-technische Untersuchungen) for scientific research in Neubabelsberg near Berlin, in which the inventor, Alfred Wilm, was the superintendent of the metallurgical section.

In 1903 the task was given to this institute by one of its founders, the German War Munition Factories of Berlin and Karlsruhe, to find an aluminum alloy suitable for making cartridge cases for hand firearms. The discovery of duralumin was announced in 1909 and was patented in 1912 under the number DRP244554. To what extent duralumin satisfied the requirements will be explained later.

On the retirement of Professor Stribeck from the directorship of the institute in 1909, the metallurgical section was discontinued. Engineer Alfred Wilm took over all existing patent rights and the Düren Metal Works obtained, as the successor of the German War Munition Factories, the manufacturing rights, under the patent DRP244554, for Germany, Scandinavia, Holland, Belgium and Switzerland.

The patent, D.R.P.244554, reads: "A process for making aluminum alloys containing magnesium, characterized by the fact that the alloys, after the last heating in the course of manufacture, are exposed to temperatures above  $420^{\circ}\text{C}$  ( $788^{\circ}\text{F}$ ) and then left for some time to automatic improvement." In the description it is stated that the alloys, after being heated, should be allowed to cool slowly.

It then says:

1. That the aluminum alloys, to which the process is applicable, must contain magnesium;
2. That the alloys must undergo a special thermal treatment at above  $420^{\circ}\text{C}$  ( $788^{\circ}\text{F}$ );
3. That this final heating must follow the last thermal treatment required for shaping;
4. That the final heating must follow immediately after cooling (either in the air or by plunging in water);
5. That the material, after being thus treated, must be allowed to rest for some time;
6. That moderate shaping is allowable before seasoning, but more violent shaping is inadmissible, because it impairs the product;
7. That the tempered material must be only moderately heated.

In the description, attention is also called to the favorable effect of small additions of heavy metals, like copper, nickel, titanium and manganese on the strength of the alloys.

The process is applicable to alloys consisting only of aluminum and magnesium. Such alloys are made in the Düren Metal Works and it is by the comparison of their properties with the properties of pure aluminum that the effect of the small addition of magnesium is most easily perceived, because, in this case, the effect of no other components, like copper and manganese, has to be taken into account. It would, however, take us beyond the limits of the

present article to discuss all these alloys and I will therefore confine myself to the most important duralumin alloys for industrial purposes, which contain copper and manganese, in addition to aluminum and magnesium.

### Properties.

The metal worker would prefer to employ as few alloys as possible, but the problem of finding a universal alloy, combining all the desired properties, must remain unsolved. In order to meet the various requirements, he must make several duralumin alloys, differing but slightly in their content of copper and manganese and all having the same content of 0.5% of magnesium. The copper content varies between 3.5 and 4.5% and the manganese content between 0.25 and 1%. Both copper and manganese add strength, but manganese increases the hardness and decreases the capacity for bending and shaping, so that the amount of manganese which can be advantageously added to duralumin alloys is necessarily small. This is unfortunate, since manganese is the component which gives duralumin its relatively high resistivity to the action of the weather and of sea water.

These alloys, when cast in sand, exhibit no better properties than the older, zinc-containing, aluminum alloys commonly used for castings. They can not be tempered and, for this reason, duralumin is not prepared in the form of castings.

Even chill-mold castings, which have a finer texture than sand castings, are scarcely affected by heating and cooling. Only in very thin sheets, which have no practical use, does tempering pro-

duce any noticeable effect. If tempering is desired, the metal must be given, while hot, a thorough preliminary forging, rolling, or pressing. The more thoroughly this is done, the greater will be the gain in strength from the final heating and cooling.

Many forgings, swaged pieces and hot-pressed sections require no supplementary cold treatment. On the other hand, sheets and strips, which often need to be thin, and tubing and wires must be rolled or drawn cold, after being worked hot. These products can therefore be previously tempered, if they have the proper thickness. Since an increase in strength and hardness is possible at the cost of ductility, the metal sheets, strips, wires and tubes are subjected to moderate compression or tension after tempering, if a greater strength and hardness is desired than can be obtained by tempering alone.

In referring to the patent description, I stated that the material could either be cooled rapidly, by plunging it into a liquid, or allowed to cool slowly in the air. The first method yields a stronger metal and should be employed, unless the metal is very thin, so that it cools quickly in the air and would be greatly distorted by plunging into a liquid. It should be remembered that the breaking strength of the air-cooled metal is from 3 to 4 kg (6.6 to 8.8 lb.) less per square millimeter than that of the liquid-cooled metal.

Heating for the purpose of tempering is best accomplished in a salt bath. It may, however, be done in a muffle furnace, but the

salt bath affords the best guaranty of uniform heating. The length of the heating depends on the thickness of the object to be tempered. Thin sheets require about 15 minutes and thick-walled objects about twice as long. The best temperature is about  $500^{\circ}\text{C}$  ( $932^{\circ}\text{F}$ ). The patent mentions a tempering heat of  $420^{\circ}\text{C}$  ( $788^{\circ}\text{F}$ ). I will explain later why this lower temperature was given.

The strength, hardness and ductility are the same, whether the tempering is done on hard-rolled or annealed objects. A tempered object can be annealed and retempered indefinitely. The tempered metal always exhibits the same characteristics, provided the degrees of heating and cooling were the same.

The three above-mentioned alloys, sold under the designations 681B 1/3, 681B and Z, have, in the rolled and annealed condition, breaking strengths of 22-24  $\text{kg/mm}^2$  (31292-34136 lb./sq.in.), with 12-15% elongation and a hardness of 60 to 65 by the Brinnell ball-test. These are noteworthy characteristics in comparison with pure aluminum which, in the annealed condition, has a breaking strength of only 10-11  $\text{kg/mm}^2$  (14224-15646 lb./sq.in.), with 35% elongation and a hardness of about 28 by the Brinnell test.

Cold-rolled pure aluminum has a strength of about 16.5  $\text{kg/mm}^2$  (23469 lb./sq.in.) at its limit of elasticity, 20.5  $\text{kg/mm}^2$  (29158 lb./sq.in.) breaking strength, 5-6% elongation and a hardness of 55. The three above-mentioned alloys, after tempering and seasoning, have the strength characteristics exhibited in the following table:



Strength Characteristics of Duralumin made According to  
the German Patent No. 244554.

Alloy	Delivery condition	Elastic limit + 20% remaining elongation kg/mm <sup>2</sup> lb./sq.in	Breaking strength* kg/mm <sup>2</sup> lb./sq.in.	Elongation $l = 11.3 \sqrt{F}$ Per cent
681 B 1/3	Tempered	24 to 27 34136-38403	38 to 41 54049-58316	18 to 21
	Cold-pressed Hardness 1/2	30 to 32 42671-45515	40 to 44 56894-62583	14 to 16
681 B	Tempered	26 to 28 36981-39826	38 to 42 54049-59739	18 to 20
	Cold-pressed Hardness 1/2	32 to 34 45515-48360	43 to 46 61161-65428	12 to 15
Z	Tempered	27 to 29 38403-41248	41 to 44 58316-62583	17 to 19
	Cold-pressed Hardness 1/2	33 to 35 46938-49782	44 to 47 62583-66850	10 to 14

Alloy	Gross-section decrease* Per cent	Impact test cm-kg/cm <sup>2</sup> in.-lb./in. <sup>2</sup>	Brinnell ball test for hardness	Modulus of elasticity kg/cm <sup>2</sup> lb./sq.in.
681 B 1/3	18 to 30 mean 26	140 to 158 784.0-884.8	115	650000 to 720000 9245275-10240920
	12 to 28 mean 22	115 to 145 644.0-812.0	122	" to " " -- "
681 B	15 to 30 mean 24	132 to 149 739.2-834.4	118	710000 to 740000 10098685-10525390
	11 to 27 mean 19	105 to 116 588.0-649.6	125	" to " " -- "
Z	14 to 28 mean 22	100 to 115 560.0-644.0	120	" to " " -- "
	10 to 26 mean 18	88 to 100 492.8-560.0	128	" to " " -- "

\* The higher values were obtained with thin samples.

The upper lines give the strength characteristics of the simply tempered metal, while the lower lines show how these characteristics are increased by a small cold compression, which we designate with "hardness 1/2". These are equal to the strength characteristics of good ingot iron.

Strength and hardness can be considerably increased at the expense of elongation, the strength of alloy 681 B, e.g., to about 50 kg/mm<sup>2</sup> (71118 lb./sq.in.) at the limit of elasticity and 60 kg./mm<sup>2</sup> (85341 lb./sq.in.) breaking strength, with about 3% elongation and a hardness of 153.

Before the announcement of the D R P 244554 in 1909, neither scientists nor practitioners ever imagined that alloys containing over 90% aluminum, with such remarkable strength characteristics, would ever be produced. The highest strength characteristics up to that time had likewise been obtained by a process originated by the "Zentralstelle für wissenschaftlich-technische Untersuchungen" at Neubabelsberg and protected by patent DRP 170085. These characteristics were: after tempering, about 28 kg/mm<sup>2</sup> (39826 lb./sq.in.) breaking strength with 20% elongation; after rolling, 32-34 kg/mm<sup>2</sup> (45515-48360 lb./sq.in.) breaking strength with 4-5% elongation. The process made known by the DRP 244554 patent is a discovery of extraordinary importance for metallurgy and, though it is now known that magnesium can be replaced by other metals, the fact remains that, in order to obtain such good results, we still have to employ the processes first made known by the above-mentioned pat-

ent. I doubt whether it will ever be possible to dispense with these processes in the production of high-grade aluminum alloys having a high content of aluminum.

#### Increasing the Hardness by Tempering.

We are not yet sufficiently acquainted with the structural changes which occur in metals with the lapse of time. Microscopic pictures furnish only slight clues. I will simply show you today, by means of two examples, the course of hardening during the process of tempering.

The experiments, forming the basis of Fig. 1, were performed with rolled samples of alloy 681 B, which were cold-rolled, after being heated to about 300°C (572°F). The samples all had the same hardness before heating. They were first heated in an oil bath, then in a paraffin bath and, lastly, in a salt bath. The samples were in each bath for about 20 minutes. They were not liquid-cooled, since the object of the experiments was simply to determine the effect of heat. Immediately after the cooling of the small samples, the resulting hardness was determined by three ball-tests and, after seasoning for 15 days, the tests were repeated. The hardness increased between 100 and 180°C (212 and 356°F) and then decreased to about 300°C (572°F). Between 300 and 350°C (662°F) there was no considerable increase nor decrease in hardness. The best annealing temperature for the tested alloy lies within these limits. Up to 350°C (662°F) the immediately determined hardness

was exactly the same as after five days. From about  $360^{\circ}\text{C}$  ( $680^{\circ}\text{F}$ ) there was rapid increase in hardness and the difference between the hardness, as determined immediately and then after five days, remained nearly constant up to  $520^{\circ}\text{C}$  ( $968^{\circ}\text{F}$ ), which gave nearly the maximum hardness. At  $420^{\circ}\text{C}$  ( $788^{\circ}\text{F}$ ) the metal had the same hardness as before heating.

Up to  $360^{\circ}\text{C}$  ( $680^{\circ}\text{F}$ ) there was a decrease in hardness similar to that observed in other metals and alloys, but at this point the small addition of magnesium caused a reversal of the hardness curve. Heating above this point greatly increased the hardness and strength, with still further increases during the five days of seasoning.

Fig. 2 shows the course of the hardening for the different time intervals. The axis of the ordinates gives the hardness according to the Brinnell method. The axis of the abscissas gives the seasoning time in hours and days. The hardening proceeds rapidly for the first four hours. During the first 24 hours it increases from 76 to 108. It reaches 112 at the end of the second day and continues to increase slightly up to the end of the fifth day. If it is desired to obtain a uniform product with the maximum strength characteristics, no manipulation requiring much change in form must be undertaken before the seasoning is completed.

The strength curve is similar to the hardness curve. In urgent cases it is not necessary to wait five days, since the seasoning is nearly complete at the end of two days. Such cases should be exceptional, however.

Manufacture

Duralumin is produced in the form of sheets, strips, washers, rods, tubes, wires and cables; pressed, rolled and drawn sections; forged and pressed pieces; rivets, nails and pins; machine screws and wood screws.

In addition to the strength characteristics given in the foregoing table, duralumin has the following physical properties. The specific gravity of the alloys under consideration is about 2.8. Its coefficient of linear expansion is 0.000026. Its heat conductivity is about 35% of that of pure copper.

The malleability of duralumin is good. The best forging temperature is about  $470^{\circ}\text{C}$  ( $878^{\circ}\text{F}$ ). A simple practical method for determining this temperature is the glowing of paper or sawdust brought into contact with the metal. Duralumin has no critical temperature, like malleable brass containing less than 60% copper. The forging may therefore be long continued without risk. Swaging requires more operations than iron or brass, because duralumin is shaped with difficulty. The heating is done best in a small muffle furnace, but can be done in a forge fire of coke.

Stamping, drawing and bending of the tempered duralumin in the cold condition are possible within certain limits, but are difficult in comparison with soft steel and brass. Sharp edges must be avoided. The radius of bend should not be less than thrice the thickness of the sheet.

The malleability of duralumin at 300-350°C (572-662°F) is good. This kind of working necessitates, however, another tempering of the finished articles. Large consumers of duralumin therefore have their own salt baths for this purpose.

Heating the tempered duralumin above 180°C (356°F) decreases the strength. At 300-350°C (572-662°F) the strength is diminished about 50%. A sharp supervision of the workmen, to prevent their misuse of the soldering lamp in sheet-metal work, and frequent instruction of the superintendents and workmen, on the unfavorable effect of heating, is desirable.

Duralumin can be welded and soldered. Even in the most favorable case, however, the weld is only about half as strong as the rest of the metal. The ductility of the seam is small and variable. In the neighborhood of the seam, which is produced at a temperature of about 650°C (1202°F), there is a region in which the metal had a temperature of 300-350°C (572-662°F), and was therefore annealed.

A duralumin weld has the structure of a casting and can not be strengthened by subsequent hammering and tempering. The welding or soldering of duralumin should therefore be avoided and unions should be made with rivets or screws (Compare "Zeitschrift für Metallkunde," 1923, Vol. 15, p.286).

Rivets are made from a special alloy having a shearing strength of 26-28 kg/mm<sup>2</sup> (36981-39826 lb./sq.in.). Rivets for parts coming in contact with sea water, like seaplane hulls and floats, must have, as nearly as possible, the same composition as the neighbor-

ing metal, in order to prevent the deterioration of the rivet heads through galvanic action.

The chemical characteristics of duralumin differ from those of pure aluminum. This subject does not, however, come within the scope of the present article. It is noteworthy that duralumin, unlike pure aluminum, is not readily affected by mercury.

The resistance of duralumin to the corrosive action of sea water is relatively good. It is better than that of any other known light metal. Iron in combination with duralumin protects the latter from the action of sea water. Detailed experiments, made by the Berlin Municipal Department for Hygienic and Economic Research, demonstrated that duralumin is not injurious to health and is therefore suitable for the manufacture of cooking utensils.

The resistance of duralumin to atmospheric action is good. Through experiments covering a period of about five years, it was found that specimens in the form of rods of 10 mm (.39 in.) diameter, flat bars of 5 (.197) and 2 mm (.0787 in.) thickness and wires of 5 and 2 mm diameter suffered no loss in strength and ductility. They hung the year round on the roof of one of our factory buildings exposed to all sorts of weather.

The strength and ductility of duralumin are favorably affected by temperatures below the freezing point of water. The strength increases with decreasing temperature. In an experiment at  $-190^{\circ}\text{C}$  ( $-310^{\circ}\text{F}$ ), the strength was found to have increased from 42 kg/mm<sup>2</sup> to 53 kg/mm<sup>2</sup> (59739 to 75385 lb./sq.in.) and the elongation from 22

to 29%. The shock strength remained unaltered. This fact is important in aircraft construction.

I have made a series of fatigue tests with duralumin and will publish the results during the summer in the "Zeitschrift für Metallkunde." I will only mention here that duralumin gave better results than soft steel, phosphor-bronze ( $\text{Cu}_{92} \text{Sn}_{28}$ ), and "tombak" ( $\text{Cu}_{72} \text{Zn}_{28}$ ).

### U s e s.

In the spring of 1914, the navy and, subsequently, the military administration stipulated the exclusive use of duralumin in the construction of the airships ordered of the Zeppelin company at Friedrichshafen. Thus a new and very large market was provided for duralumin. The whole framework of the airships was made of duralumin in the form of thin U and angular sections and still thinner bracing strips. During the war we supplied the material for more than 80 airships, over 750 metric tons (1653465 lb.) in one year.

When, during the course of the war, the building of airships for the army and navy was reduced, metal airplanes came into use and the demand for duralumin for this purpose increased greatly during the last year of the war. A great deal of duralumin is still used in building airplanes. Unfortunately, the development of German airplane construction is restricted by the Treaty of Versailles to the production of commercial airplanes of a certain size and speed, thus reducing the demand for materials.

There is an increasing demand for duralumin for the connecting-



rods of automobile internal combustion engines, for which purpose it has the following advantages:

1. A 30-35% saving in weight for the same safety factor;
2. About 30% increase in the revolution speed of the engines;
3. About 10% increase in engine power for the same carburetor adjustment;
4. An increase in the maximum speed, or
5. A greater climbing capacity on mountains;
6. Rapid dispersion of superfluous heat;
7. Less pressure on the bearings and consequent lessening of friction;
8. Greater ease in starting engine;
9. Greater elasticity of engine;
10. Smoother functioning of engine, with less vibration, and, consequently,
11. Longer life of both engine and vehicle.

Duralumin is also used for other engine parts and in the construction of automobile chassis and bodies. The Zeppelin Boat Yard at Staaken, near Potsdam, uses duralumin extensively in the hulls of boats and also in the body of a small motor car. Duralumin is employed in centrifugal machines, optical instruments, electrical and orthopedic appliances, compressors, magnetos, life-saving apparatus, jewelry, etc.

The previously mentioned object, which led to the discovery of duralumin, namely, the production of a suitable alloy for the manufacture of cartridge cases, was only partially successful. The

German War Munition Factories in Karlsruhe made duralumin cartridge cases which were capable of being fired and which stood the test of storing. They showed a tendency, however, to burn through at the base. Since this serious defect is due to the low melting point of duralumin ( $650^{\circ}\text{C}$  or  $1202^{\circ}\text{F}$ ) which can not be raised, the prospects for duralumin cartridge cases are small.

I prophesy a great future for the aluminum alloys made according to the German patent 244554, but this future lies in other fields, which can only be conquered by patient and persevering work.

#### Rivets Made from Aluminum Alloys.

At the request of the Bureau of Aeronautics of the American Navy, the properties of rivets made from aluminum alloys were thoroughly tested (See Foundry Trade Journal, 1923, Vol. 28, p. 333). The analyses of the samples showed the following compositions:

Percentage Composition of Rivets.

Metal	1	2	Metal	1	2
Si	0.33	0.28	Fe	0.52	0.52
Cu	0.89	0.54	Mg	0.00	0.00*
Mn	0.32	0.14	Al	Rest	Rest

\* Or traces.

It is, therefore, not necessary to employ very soft rivets of nearly pure aluminum, since good results were obtained even with cold-drawn and annealed wire made from an alloy containing 3% of

copper, 20% zinc and 77% aluminum, or with duralumin wire. Rivets made from these alloys are better than those made from pure aluminum wire, since they have a greater shearing strength. After being in use many months, they have shown no tears nor other defects.

Rivets made from cold-drawn wire, composed of 3% Cu, 20% Zn and 77% Al, and heated to 250°C (482°F) have the greatest shearing strength of 270 kg/cm<sup>2</sup> (3840 lb./sq.in.), while values of 200-220 kg/cm<sup>2</sup> (2845-3129 lb./sq.in.) were obtained with rivets made from hot-drawn duralumin wire. The first-mentioned rivets are preferable, because they may be used at any length of time after the thermal treatment and do not require retempering. Duralumin rivets should be used as quickly as possible after tempering and are comparatively difficult to tighten. This difficulty may be remedied by employing a somewhat softer alloy (2.25% Cu, 0.5% Mg, 96.75% Al, 0.5% Mn) which requires a thermal treatment similar to that required by duralumin.

Translation by Dwight M. Miner,  
National Advisory Committee  
for Aeronautics.

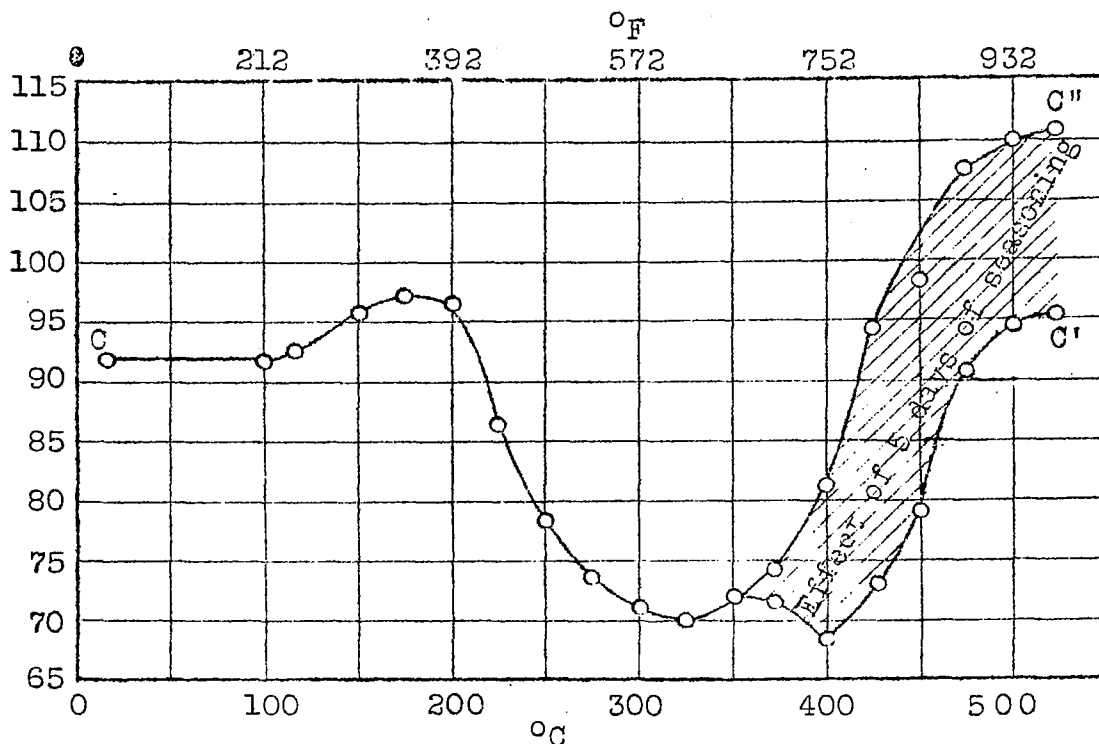


Fig. 1 Brinell hardness. Breaking strength 40.4 kg/mm<sup>2</sup> (57463 lb./sq.in.) Elongation 10.1 %. Course of heat curve of an aluminum alloy containing magnesium. Thermal effect without cooling in liquids. Breaking strength of cold-rolled sheet = 34.3 kg/mm<sup>2</sup> (48787 lb./sq.in.) Minimum tempering temperature. Elongation 2.9 % Curve C-C'-C'' 93.2 % Al, 0.52 % Mg 4.28 % Cu, 1.07 % Mn treated according to patent DRP 244554

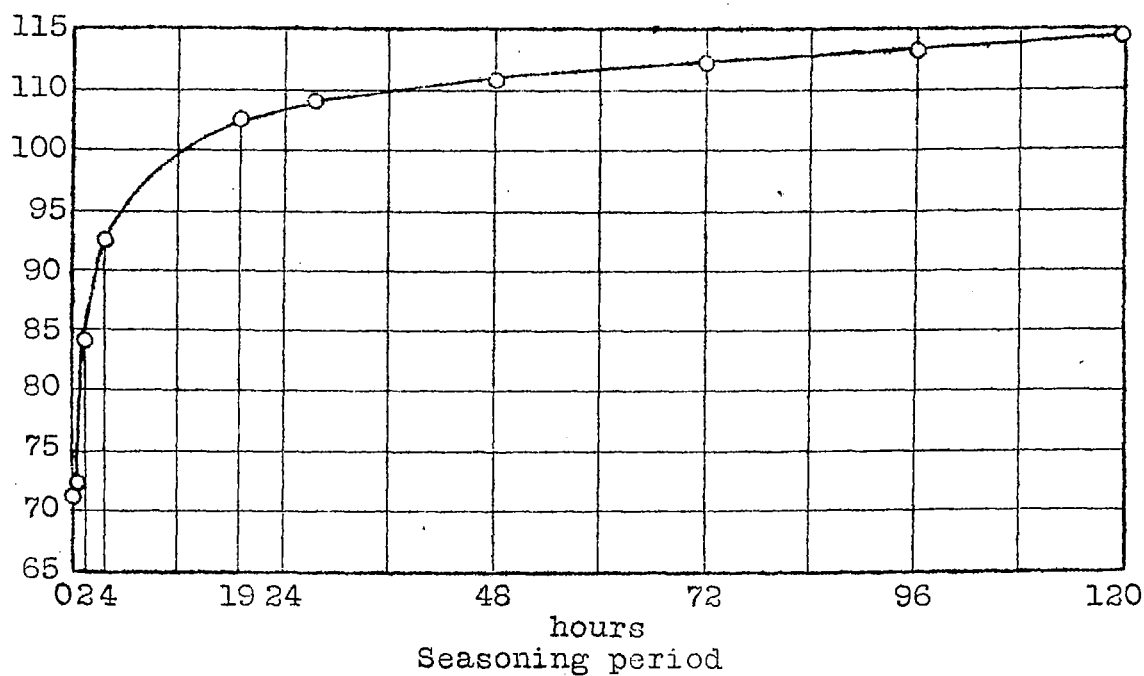


Fig. 2 Effect of seasoning. Brinell hardness. Alloy containing 4.5 % Cu and 0.57 % Mg. Effect of seasoning period on hardness of tempered duralumin.

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